Microwave Engineering
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Lecture 37
Satellite Communication

So, we have seen two applications of microwave, namely radar and wireless communication. Let us now come to another application of microwave frequencies, which is satellite communication.

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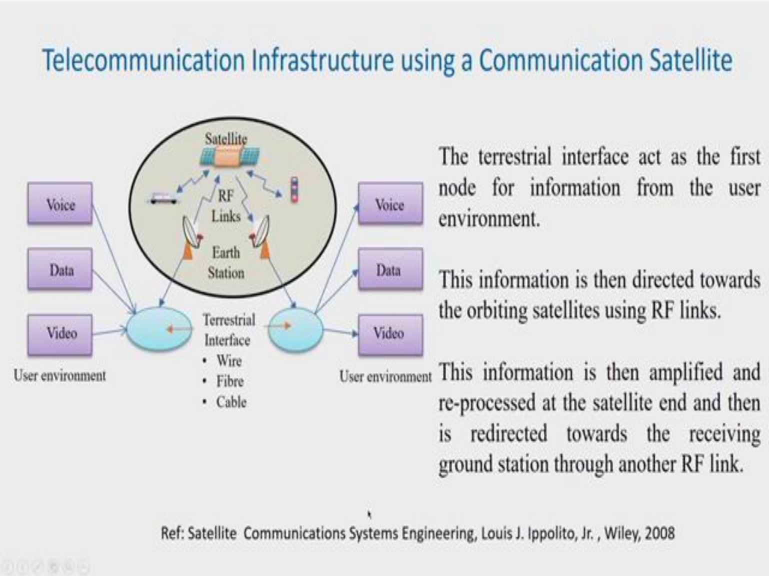

Satellite communication became possible in mid-1960s, and after that there has been tremendous growth in communication satellites in use of communication satellites. And not only for communication purposes, satellites are used for navigational and other purposes also. Here, our discussions will be limited to communication satellites. So, here we show the telecommunication infrastructure using a communication satellite. We can see that the satellite is essentially a repeater in space.

And, then we have terrestrial interfaces, and then through this terrestrial interfaces the traffic in the form of voice data video, these are transmitted using an earth station to a satellite. And, then the satellite transmits it back to another earth station, and it then comes to terrestrial interface, through which this voice data video these are delivered to the users. In the earlier days, terrestrial microwave links were developed. The range of this type of link was limited because of the curvature of the earth.

And, to overcome this, we required to increase the height of the tower where the antennas are mounted. So, beyond 40, 50 kilometers the tower heights become very large. And, therefore instead of going for single link, the repeaters were used. And in fact, the long-distance coverage before the advent of satellite communication, one of the major means of providing long-distance coverage was through terrestrial microwave links. Although these are used nowadays also, their usage has become limited after the introduction of satellite. Now, we will see that the satellites are put in orbits, which are several 100 to several 1000 kilometers above the earth, and therefore they can provide coverage to a much wider range.

So, coming back to this diagram the terrestrial interface act as the first node for information from the user environment. This information is then directed towards the orbiting satellites using RF links. And, this information is then amplified and reprocessed at the satellite ends. And, then is redirected towards the receiving ground station through another RF link. It may be noted that the frequency that we use for transmitting signals from transmitting earth stations to the satellite. It is different from the frequency that is used for transmitting signals from satellite to the receiving earth station. And, therefore we have a translation of frequency takes place in the satellite. We will discuss more about it.

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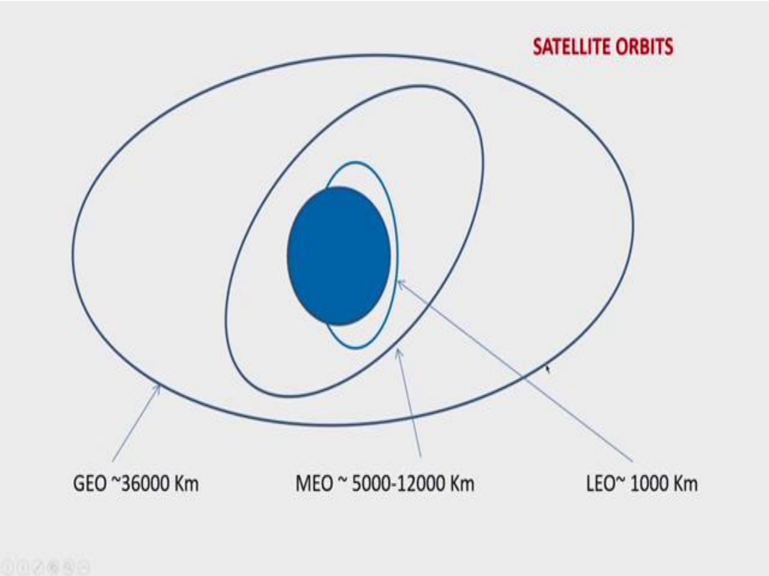

Now, the orbits in which the satellites are placed can be at various heights. We have LEO satellites or low earth-orbiting satellites, which are around 1000 kilometers. Then we have an MEO or medium earth orbit satellites, which can range from 5000 kilometers to 12000 kilometers. And, finally we have GEO, the GEO stationary orbit, which is about 36000 kilometers from the earth. And this is in the equatorial plane of the earth; this is called GEO stationary because in this orbit the when a satellite is placed it remains fixed above a point on the earth's surface.

Whereas in an LEO or MEO type of orbits, the satellite moves with relative to the earth. And, it is visible from a particular location only for a fixed period of time, and it completes several rotation around the earth in a day. Whereas in GEO stationary orbit, the satellite moves along with the earth and appears a stationery form a point on the earth's surface. These GEO stationary satellites are extensively used for communication purposes. And, this orbit is actually having large number of satellites, and the satellites are placed as close as a degree on this orbit.

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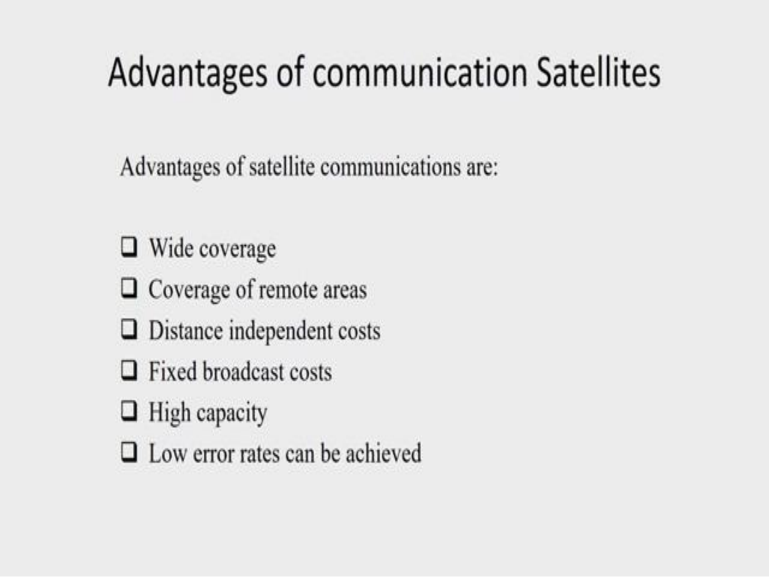

Now, there are several advantages of communication satellites. As I have already mentioned, the satellite being at a height from the earth's surface can provide wide coverage. And, also these type of communication satellites are useful for coverage in remote areas, where terrestrial coverage become difficult. For example, if we have an isolated village in some hilly terrain, it can be covered from satellite. It may be difficult or economically not viable to have terrestrial coverage in the form of fiber or cables being laid and getting such areas connected. In satellites communication has the advantage of distance independence costs. Broadcast costs are also fixed, and it provides such communication infrastructure that provides very high capacity. And, low error rates can be achieved with satellite communication systems.

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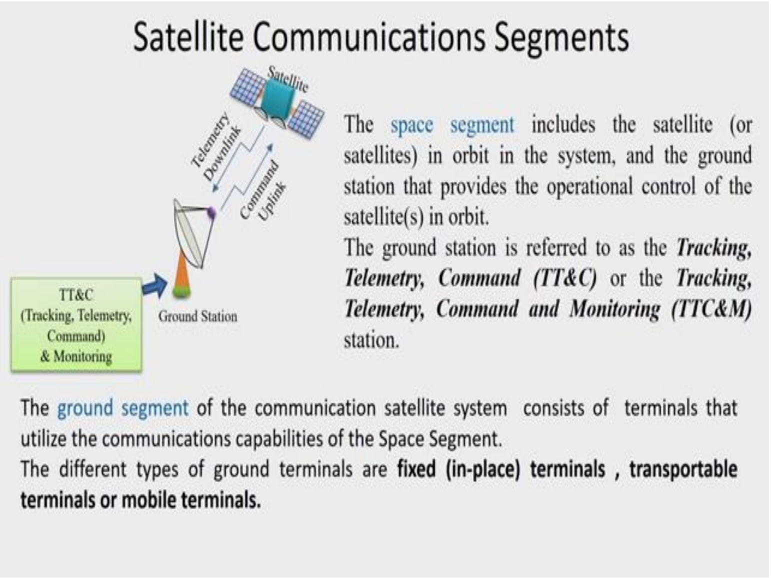

Let us now talk about the satellite communications segments. We generally talk of space segment which includes, the satellite or satellites in orbit and the ground station that provides the operational control of the satellites in orbits. So, the ground station is referred to as tracking telemetry command, or the tracking telemetry command and monitoring station. So, apart from normal communication payload, the satellite also has to have links that have provisions for sending commands uplink and telemetry signals downlink.

The ground segment of the communication satellite system consists of terminals that utilized the communication capabilities of the space segment. So, in communication space segment we have the satellites which can provide us communication channels. And the ground segment has terminals that can make use of these channels. And we have different types of ground terminals like we can fixed terminals, we can have transportable terminals. Transportable once can be moved from one location to the other but, when they communicate they remain fixed. Whereas mobile terminals can communicate with the satellite when they are moving.

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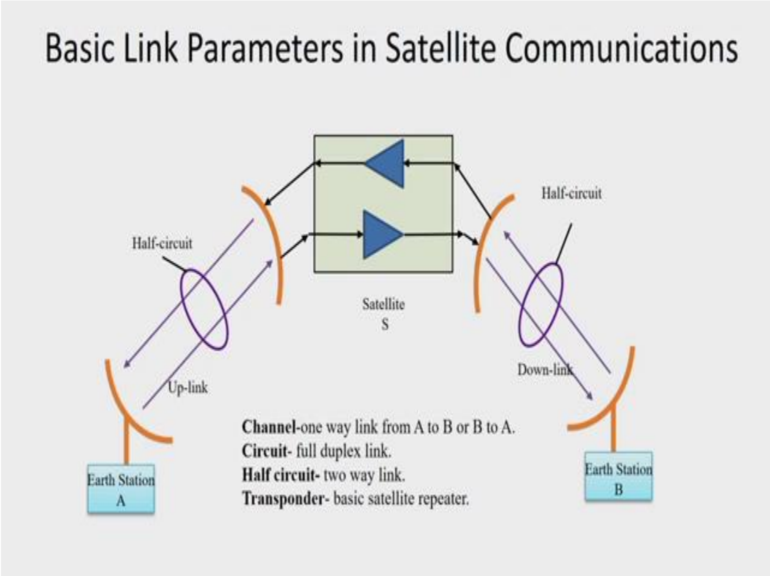

So, if you look at the basic link parameters in a satellite communication system. We can see that we have a channel, which is a one-way link from A to B, A, and B are the 2 earth stations. So, a channel actually forms a link from earth station A to B through the satellite but, it is a one-way link. A circuit this terminology used to denote a duplex link 2-way communication from one earth station to another earth station. A half circuit is a 2 say link between an earth station to the satellite. And, this basic repeating operation in the satellite is performed using a transponder. Now, let us try to see how a transponder works to some detail let us try to see how this transponder works.

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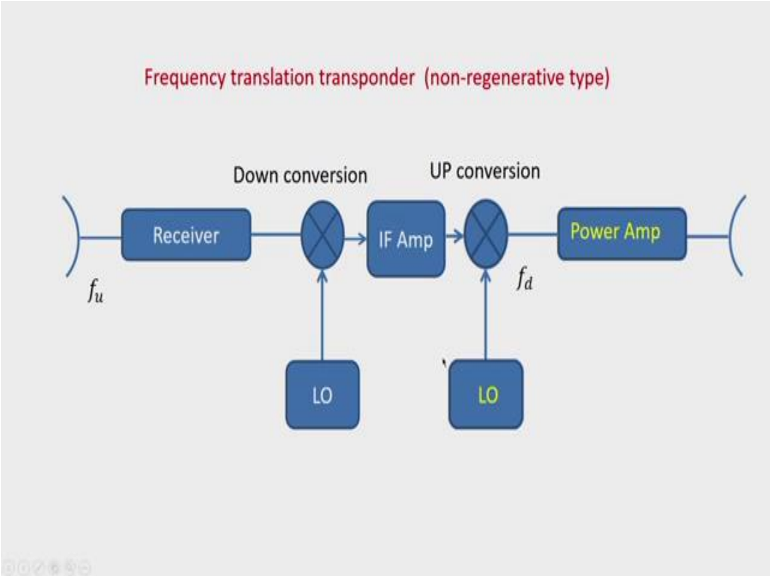

And, here comes the need for designing circuitry in a microwave frequency band. Because in the transponder, we can see we have an antenna, f_u is the uplink frequency. Then we have a receiver, which might consist of the bandpass filter, LNA. And, then we have down conversion of this frequency to some intermediate frequency by multiplying with a local oscillator. And, then the amplification is performed at the intermediate frequency. And, after amplification it is upconverted to another frequency $f_{d,}$ which is downlink frequency. And, here then it is given to a power amplifier where the signal power is raised to appropriate level for transmission, and then it is transmitted to the earth station located in the ground.

Now, these devices particularly this power amplifier, it must provide enough power so that detectible signals are obtained. And, if you remember, the distance for a GEO stationary satellite was 36000 kilometers. So, what we required that enough power of transmitted so that the signal can cover this distance and still remain detectable at the ground station. So, this type of transponder does the frequency translation only, and of course it amplifies the signal. This is called a non-regenerative type.

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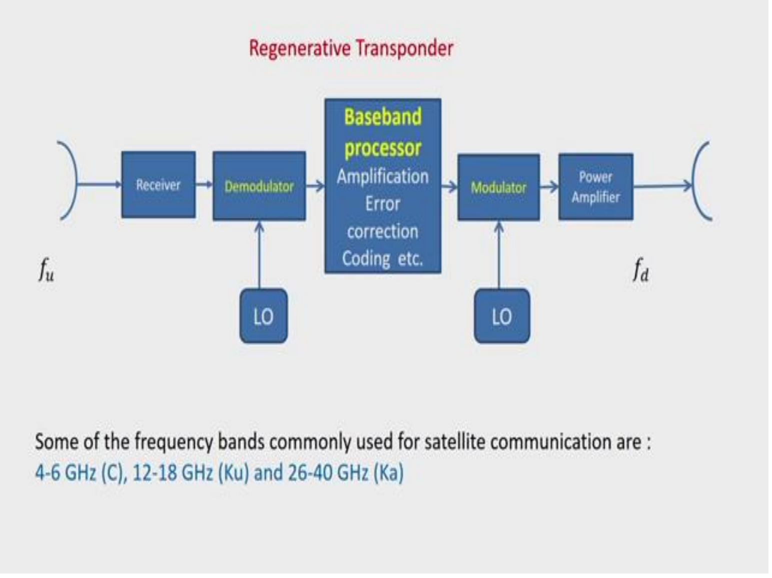

There is another variety of transponder, which is called a regenerative transponder, so after receiving the signal it is demodulated. The demodulator consists the down conversion unit also, and local oscillator is connected here. So, after down-conversion and demodulation, the signal is given to a baseband processor, where it is amplified, error correction is made, it also does coding and many other functions. After that it is given to a modulator, and by using this local oscillator, it is also modulated and upconverted. Finally this upconverted signal from baseband to the desired frequency, this signal will be amplified by the power amplifier, and then it will be given to antenna for transmission. So, we see that in a regenerative transponder it is not only the frequency translation from f_u to f_d signal actually gets demodulated.

Then, a lot of baseband processing is done it is demodulated and upconverted and given to the power amplifier. Now, some of the frequency bands which are commonly used for satellite communication are a very popular band is a 4 to 6 gigahertz band. Another band is 12 to 18 gigahertz, which is Ku band, and the other band is 26 to 40 gigahertz Ka-band. Many a time, the band which is selected for satellite communication based on several considerations like, the attenuation that occurs to the signal because of absorption. So, in fact we have low attenuation windows, and usually the frequencies in these windows are preferred for long-distance satellite communication.

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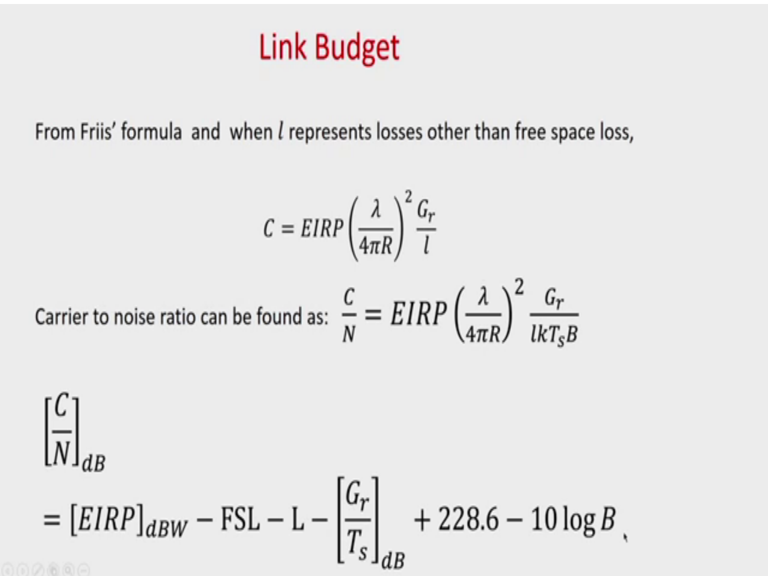
$$C = EIRP\left(\frac{\lambda}{4\pi R}\right)^2 \frac{G_r}{l}$$

Carrier to noise ratio can be found as: $\frac{C}{N} = EIRP\left(\frac{\lambda}{4\pi R}\right)^2 \frac{G_r}{lkT_sB}$

$$\left[\frac{C}{N}\right]_{dB} = [EIRP]_{dBW} - \mathrm{FSL} - \mathrm{L} - \left[\frac{G_r}{T_s}\right]_{dB} + 228.6 - 10\log B$$



Now, how to determine the power that we required to transmit? Say from satellite to the ground earth station, so this is calculated using link budget calculation. And, we outline a simple link budget calculation from Friis formula and if we consider this small l representing the losses other than free-space loss. We have seen that the signal becomes weak when it propagates because of spreading, which we call free space loss.

Other than that, there are several other losses as we have mentioned, there is absorption due to gaseous particle may be absorption due to rainfall, so all these losses are accounted by l. Then this C usually is denoted as carrier power; it is equal to EIRP. EIRP is the effective isotropic radiated power. And, essentially represent the term Pt into gt in Friis formula. And, then lambda by 4 pi R whole square into G_r divided by l.

Now, in the link budget calculation of satellite, we find out one quantity which is called C by N carrier to noise ratio. And, once we have the expression for C the carrier to noise ratio becomes this expression divided by kTsB where k is the bondsman constant, Ts is the receiving antenna system temperature, and B is the bandwidth. Now, if we express C by N in dB then we will have EIRP expressed in dB watt minus free space loss in dB.

Free space loss will be calculated as 20 log 4 pi R by lambda, then this other losses L in dB, then Gr Ts again in dB. And, 10 log 1 by k, this will give this figure 228.6, and this bandwidth B to the power minus 1 will give minus 10 log B. So, this is the carrier to noise ratio, and it has to be properly designed. So, that we get appreciable amount of signal in the ground station so that the information can be demodulated and decoded from it.

So, briefly, this is about satellite communication and various microwave components and sources that we have discussed in our earlier lectures. They find use in satellite communication systems; we require very high gain power amplifiers, TWT type of tubes are extensively used in satellite transponder. And, also as we go towards higher and higher frequency for satellite communication, we already discuss the limitation that we face because, at higher frequency, the Friis space laws itself become very large. And, therefore we need to design very high gain antennas, highly directional antennas to make up for this type of loss.

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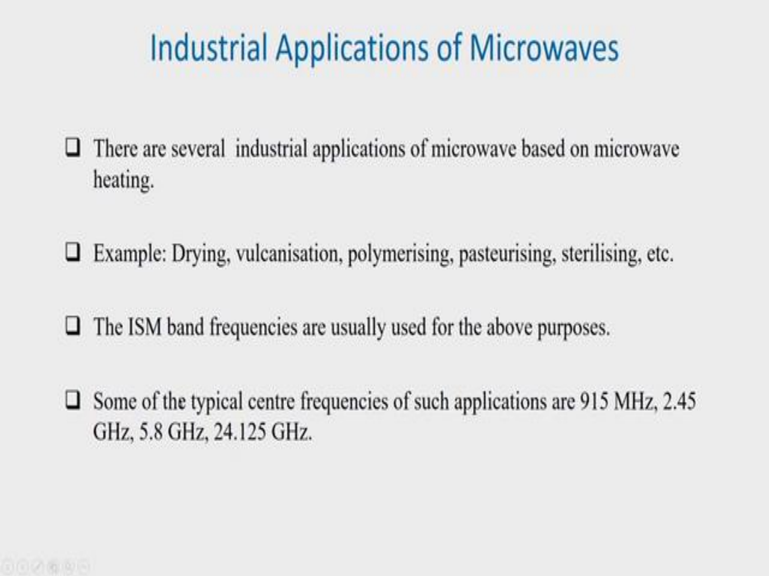

Let us now move on to the industrial and medical applications of microwaves. We start with industrial applications there are several industrial applications of microwave-based on microwave heating. And, we know that microwave oven is a very popular commodity nowadays and it works on the principles of microwave heating of material. Now, apart from that the other examples where microwave heating is utilized are drying, vulcanization, polymerizing, pasteurizing, sterilizing, etc.

So, there are several other application areas where microwave frequency is used. Usually, the ISM band frequencies are used for these purposes. ISM is an industrial scientific and medical; a set of frequencies is set aside for doing this type of activity. Some of the typical center frequencies of such applications are 915 megahertz, 2.45 gigahertz, 24.125 gigahertz, so this is the ISM band frequencies that can be used for industrial application of microwave.

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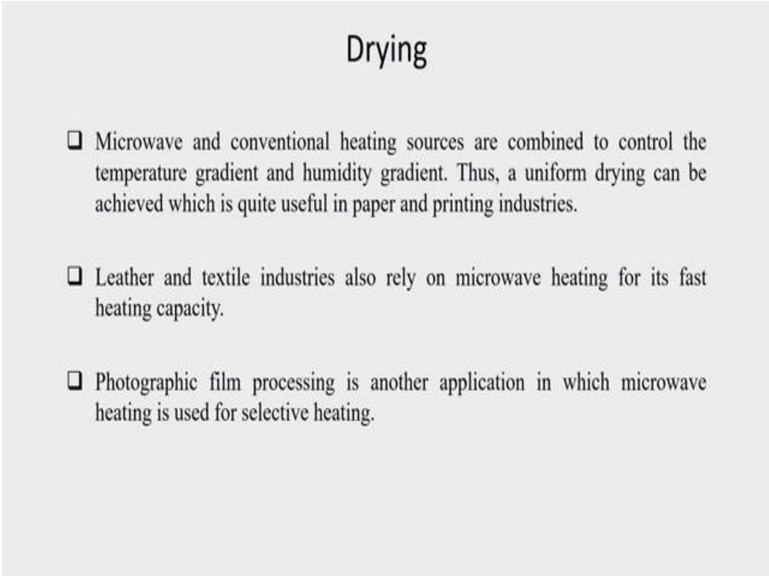

So, let us briefly discuss drying, microwave, and conventional heating sources are combined to control the temperature gradient and humidity gradient. Thus, a uniform drying can be achieved which is quite useful in paper and printing industries. Now, normally, when we heat conventional heating, the heat flows from surface where heat is applied inside the body. But, in microwave heating the whole material may be heated simultaneously both inside and outside, and therefore more uniform heating can be made. Leather and textile industries also rely on microwave heating for its fast heating capacity. Photographic film processing is another application in which microwave heating is used for selective heating.

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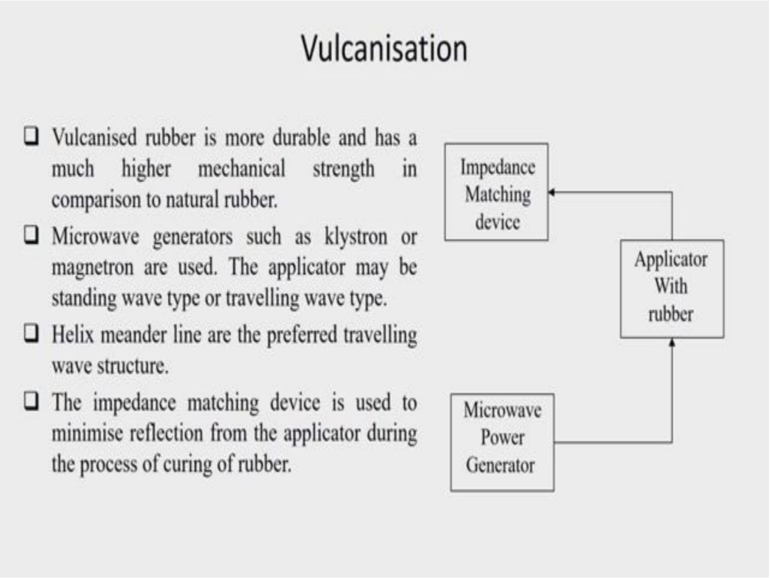

Let us now come to vulcanization, vulcanized rubber is more durable and has a higher mechanical strength in comparison to natural rubber. And, microwave generators such as klystron or magnetron are used. The applicator where the rubber is placed may be standing wave type or travelling wave type. Helix meander line is preferred when travelling wave structure is used. The impedance matching device is used to minimize reflection from applicator during the process of curing of rubber.

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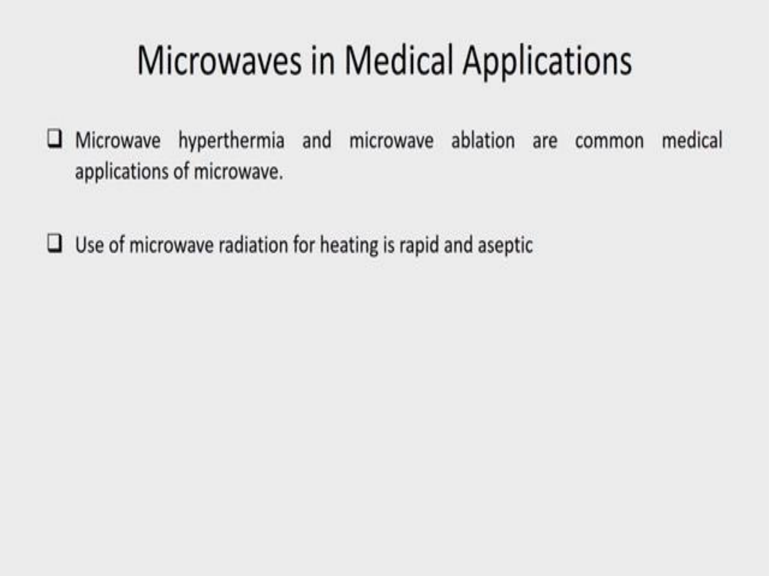

Let us now comes to some medical applications, microwave hyperthermia and microwave ablation are the common medical application of microwave. The use of microwave radiation for heating is rapid and aseptic.

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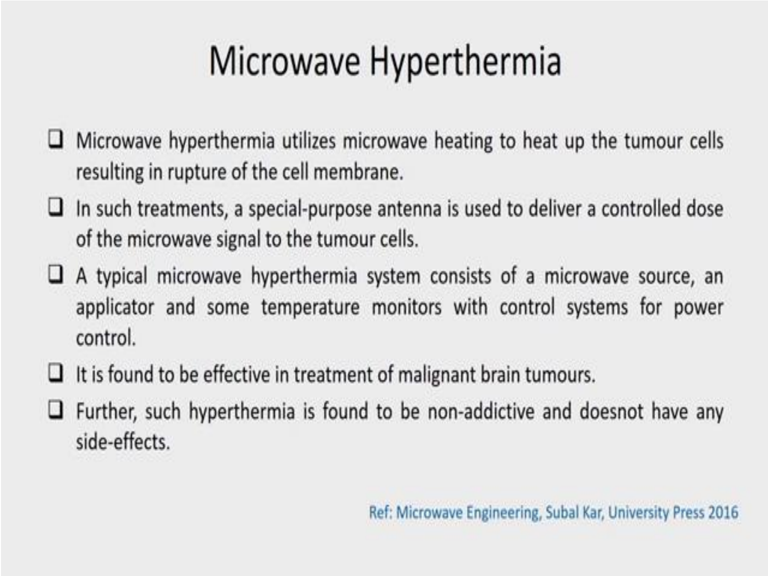

So, here we briefly discuss microwave hyperthermia. Microwave hyperthermia utilizes microwave heating to heat up the tumor cells resulting in rupture of the cell membrane. In such treatments, special purpose antenna is used to deliver controlled dose of microwave signal to the tumor cells. A typical microwave hyperthermia system consists of a microwave source, an applicator and some temperature monitors with control system for power control. It is found to be effective in treatment of malignant brain tumors. Furthers, such hyperthermia is found to be nonaddictive and does not have any side effects.

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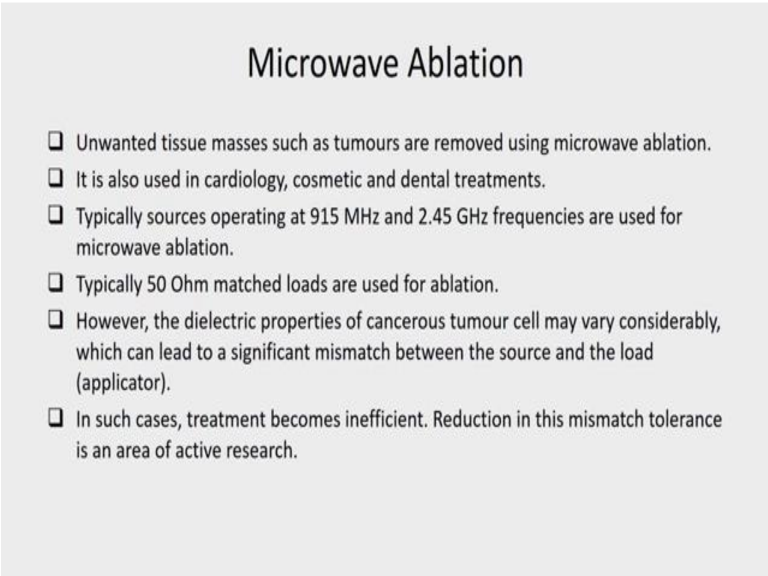

Let us briefly discuss microwave ablation. Unwanted tissue masses such as tumors are removed using microwave ablation. It is also used in cardiology, cosmetic and dental treatments. Typically sources operating at 915 megahertz and 2.45 gigahertz frequencies are used for microwave ablation, and 50 Ohm matched loads are used. Dielectric properties of cancerous tumor cells may vary considerably, which can lead to significant mismatch between the source and the load which is an applicator.

In such cases, treatment becomes insufficient. Reduction in this mismatch tolerance is an area of active research. So, with this discussion, we come to the end of this module and in fact the end of this course. We have covered various aspects of microwave engineering in this course, which is spread over 12 modules. And we have been particularly focusing on the fundamentals. So, that after doing this course the participants will have sufficient background to pursue any higher studies in this area.

Now, microwave engineering, although it is started long back and it is a very matured engineering discipline, still people are finding lots of new applications in this field, and there is various direction in which microwave engineering is expanding. Because of the huge demands of communication, the emphasis is shifting from lower microwave frequency bands, near few gigahertz to millimeter-wave frequency bands. And in fact we said that in 5G communication 5^{th} generation of wireless communication millimeter-wave communication is expected to play a vital role. It is worth mentioning here that professor, J. C. Bose way back in 1897, he was contemporary to Marconi.

And he carried out experiments whichever actually in the millimeter-wave band. So, millimeter-wave communication systems are expected to become very popular, with the advent of 5G systems of course millimeter wave is used in defense and military applications. But, large scale use of millimeter-wave of frequencies will take place, if it becomes a successful implementation in 5G technologies. So, apart from millimeter wave, another band which is above millimeter-wave and it is in the no man’s land between microwave and optics, this is also exploding, and this called terahertz band of frequencies. Even the basic microwave frequency bands around few gigahertz are also extensively used and many other devices like initially, the processors used to work in the megahertz range.

Now, almost all processors are it a desktop processor or a mobile processor; all these processors work in the microwave frequency range. Some work in 2 gigahertz, some in 2.6 gigahertz, some in 3 gigahertz. So, when the processor itself works in the microwave frequency band, many associated circuits is they also need to operate at that frequency band. So, this is another area where the frequency is increasing, and the microwave frequency is finding lot of applications. Although we are having very widespread use of microwave frequencies, at the same time excessive use of microwave frequencies, we need to be very cautious about the health and environmental hazards that may happen with the M waves in the microwave frequencies.

So, this another area where a lot of scopes exist, how to provide communication at the same time not posing any environmental or health hazards, any threat of environmental or health hazard. Another area that is related to this microwave is electromagnetic interference and compatibility. Because most of the equipment which operates in the microwave frequency band, they essentially radiate and therefore interference becomes a major issue. So, this is another direction where lot of activities are there.

So, we have seen the industrial application, we have seen the application in the field of radar, we have seen the application in field of satellite communication. So, microwave engineering knowledge in microwave engineering will be very very essential to understand all these technologies. And this is why the focus of this course has remained to provide a basic or fundamental understanding of the various principles of microwave engineering. With this I thank all the participants who have joined in this course and thank everyone who had provided me assistance in making this video course possible.